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Research Paper

PERFORMANCE AND ANALYSIS OF OFDM SYSTEMS USING 4-PSK AND 8-PSK MODULATION TECHNIQUES

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***Abstract*— Orthogonal Frequency Division Multiplexing (OFDM) is a highly efficient multicarrier modulation technique that converts a high-rate data stream into multiple parallel low-rate subcarriers to achieve high-speed transmission in delay dispersive, multipath fading channels. This paper delivers a rigorous comparative analysis and systematic evaluation of an OFDM system framework implemented using M-ary Phase Shift Keying (MPSK) schemes, specifically focused on 4-PSK (QPSK) and 8-PSK configurations. The comprehensive communication chain—comprising pseudorandom binary sequence generation, digital symbol mapping, Inverse Fast Fourier Transform (IFFT) processing, cyclic prefix insertion, Additive White Gaussian Noise (AWGN) channel emulation, receiver-side Fast Fourier Transform (FFT) processing, Euclidean distance optimal demodulation, and automated Bit Error Rate (BER) evaluation—is engineered and evaluated in MATLAB®. Performance benchmarks are strictly analyzed using theoretical thresholds, simulated BER versus Signal-to-Noise Ratio (SNR) curves, received constellation scattering charts, and spectral efficiency trade-offs. The empirical results demonstrate that while OFDM-4PSK provides exceptional noise margin robustness and minimizes communication degradation under low SNR environments, OFDM-8PSK offers a 50% enhancement in data throughput and spectral efficiency at the expense of higher SNR prerequisites to maintain matching error bounds.**

***Keywords*— OFDM, 4-PSK, QPSK, 8-PSK, Bit Error Rate (BER), Signal-to-Noise Ratio (SNR), IFFT, FFT, Cyclic Prefix, Spectral Efficiency, MATLAB Simulin.**

I. INTRODUCTION

Modern telecommunication environments, such as fourth-generation (4G) Long Term Evolution, fifth-generation (5G) New Radio, and contemporary high-speed Wi-Fi standards, require extremely robust physical-layer transmission frameworks. These systems must support high data rates while operating over demanding, frequency-selective fading visual and radio channels. Historically, conventional single-carrier transmission formats suffered severely from frequency-selective multipath fading, where distinct delayed versions of the transmitted signal arrive at the receiver array at varying times. This time dispersion causes Inter-Symbol Interference (ISI), heavily degrading communication fidelity.

Orthogonal Frequency Division Multiplexing (OFDM) effectively addresses these multipath fading challenges. The underlying architecture of an OFDM transmission block divides a high-bandwidth, high-velocity sequential bitstream into dozens or thousands of parallel, closely-spaced narrowband channels. By transmitting lower-rate components concurrently across distinct subcarriers, the absolute duration of individual communication symbols expands substantially beyond the delay profile of physical multi-path environments, inherently neutralizing the devastating effects of ISI without requiring complex time-domain equalizers.

Crucially, the overlapping placement of subcarriers within the spectrum remains perfectly valid without cross-talk because of the mathematical constraint of orthogonality. The choice of baseband digital modulation mapped to these individual subcarriers determines the operational sweet spot of the complete transmission system. Phase Shift Keying (PSK) represents a compelling modulation framework due to its fixed-envelope characteristics, which provide solid immunity against nonlinear distortions caused by High-Power Amplifiers (HPAs) at the transmitter frontend.

II. WIRELESS SYSTEM EVOLUTION

The evolution of multi-carrier technology traces back several decades, but its widespread deployment became commercially viable with high-performance digital signal processors capable of performing real-time Fourier transformations. In older communication links, spectral bands were segregated into rigid, guard-band-isolated frequencies using traditional Frequency Division Multiplexing (FDM). While effective at preventing adjacent channel interference, FDM wastes substantial spectral real estate because the guard sub-bands do not carry payload information.

OFDM eliminates this spectral inefficiency by allowing subcarrier spectra to overlap significantly. This overlap is governed by a precise mathematical condition: the subcarrier spacing is exactly equal to the reciprocal of the active symbol period. Consequently, at the peak frequency of any given subcarrier, all neighboring subcarrier spectral envelopes pass through zero. This allows tight spectral packing without introducing cross-carrier interference, resulting in up to a 50% improvement in spectral efficiency compared to classical FDM architectures.

III. TECHNICAL OBJECTIVES

The primary objective of this research is to design and analyze an integrated baseband OFDM communication simulation chain to systematically evaluate the performance differences between 4-PSK and 8-PSK modulation schemes. This work analyzes how the code behaves under varying noise conditions by executing bit-level symbol tracking and mapping.

The specific technical objectives are defined as follows: First, to develop a reusable MATLAB script executing random data stream generation, digital constellation mapping, M-point IFFT scheduling, cyclic prefix insertion, and AWGN noise injection. Second, to verify the exact mathematical relationships linking the symbol-to-noise ratio to the corresponding bit error rate under non-uniform noise conditions. Finally, to establish a comparative trade-off matrix detailing throughput advantages against noise margins to assist project teams in choosing the optimal modulation framework for varying signal conditions.

IV. MATHEMATICAL FOUNDATIONS OF M-PSK

Phase Shift Keying maps binary bit combinations to specific phase values within a constant-amplitude complex carrier signal. The general mathematical expression for an M-PSK modulated signal symbol is given by:

$$s_i(t) = A \cos(2\pi f_c t + \theta_i), \quad 0 \le t \le T_s \qquad (1)$$

where A denotes the constant signal wave envelope amplitude, f_c represents the carrier frequency parameter, T_s specifies the absolute symbol duration boundary, and θ_i denotes the targeted phase shift angle values assigned to incoming data components.

The phase angles θ_i are structured as follows:

$$\theta_i = 2\pi i / M \qquad (2)$$

where the integer indexing variable maps to i = 0, 1, 2, ..., M-1, where M defines the constellation size order. As the order value M escalates, the capacity to convey information expands, with individual symbols mapping to log2(M) binary bits. However, the geometric spacing between adjacent constellation points on the 2D complex plane decreases rapidly, introducing a clear trade-off between spectral efficiency and operational noise tolerance.

V. LITERATURE REVIEW

The foundations of practical multicarrier communications were established by Weinstein and Ebert in 1971, who demonstrated that the computational complexity of analog subcarrier oscillators could be reduced by adopting the Discrete Fourier Transform (DFT) and its computationally optimized variant, the Fast Fourier Transform (FFT).

In 1985, Cimini provided comprehensive structural analysis regarding OFDM operation within fading mobile networks, demonstrating its robustness against timing synchronization limits and fading. Further research by van Nee and Prasad expanded these models to support high-velocity wireless multimedia systems, highlighting the critical role of the cyclic prefix in preserving carrier orthogonality over dispersive channels.

Recent publications focus heavily on adaptive modulation schemes, where the system dynamically switches between modulation levels like 4-PSK and 8-PSK based on real-time channel feedback. This approach maximizes spectral efficiency across time-varying networks. This paper expands on these concepts by delivering a direct, comparative simulation benchmark between these two key modulation levels within a unified multicarrier framework.

VI. THE BASEBAND OFDM SIMULATION PIPELINE

Evaluating the system requires a complete simulation pipeline that models the entire communication chain, from source bit generation to receiver output. This section details each stage of the baseline multi-carrier model.

A. Pseudorandom Binary Sequence Generation

The simulation framework begins by generating a uniform pseudorandom binary sequence, ensuring that all combinations of 0 and 1 occur with equal probability. This sequence simulates an uncompressed data payload stream, providing an unbiased baseline for evaluating the bit error rate across different signal conditions.

B. Digital Symbol Mapping Stage

The generated bitstream is grouped into parallel blocks depending on the selected modulation order. For the 4-PSK configuration, bits are processed in pairs (log2(4) = 2), mapping to four distinct phase locations: 45°, 135°, 225°, and 315° on the complex plane. For the 8-PSK configuration, bits are grouped in triplets (log2(8) = 3), mapping to eight phase locations separated by 45° intervals (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). Gray coding is applied across both configurations to ensure that adjacent constellation symbols differ by only a single bit, minimizing bit error propagation during demodulation.

C. Inverse Fast Fourier Transform Processing

The mapped complex modulation symbols are mapped to parallel subcarriers. This block converts the frequency-domain symbol vectors into time-domain signal blocks using an N-point Inverse Fast Fourier Transform (IFFT). The mathematical transformation is defined as:

$$x(n) = (1/N) \sum_{k=0}^{N-1} X(k)\, e^{j 2\pi k n / N}, \quad 0 \le n \le N-1 \qquad (3)$$

where X(k) represents the complex digital symbol assigned to subcarrier index k, and x(n) defines the resulting time-domain discrete sample vector. This operation modulates the subcarriers concurrently while maintaining strict mathematical orthogonality.

D. Inter-Symbol Interference Mitigation Challenges

Transmitting high-rate data streams over physical channels increases susceptibility to channel delay profiles, resulting in inter-symbol interference that requires complex, power-intensive equalization stages at the receiver. Existing multi-carrier setups resolve this issue by utilizing uniform block division schemes, but performance remains tied to the selected modulation mapping order.

Current communication systems frequently use 4-PSK (Quadrature Phase Shift Keying) when prioritizing signal reliability across low-power links or satellite telemetry. Conversely, systems transition to 8-PSK maps when channel state reports show high signal-to-noise ratios, allowing enhanced data throughput over standard band allocations. Managing this trade-off requires a clear, quantifiable model comparing these modulation levels within an integrated transmission framework.

E. Cyclic Prefix Guard Band Addition

To eliminate inter-symbol interference caused by channel delay spread, the final G samples of the time-domain OFDM symbol block are replicated and appended to the front of the block. This converts linear channel convolution into a circular convolution process, simplifying equalization at the receiver.

F. Channel Emulation Block

The time-domain signal array passes through an Additive White Gaussian Noise (AWGN) channel model, which introduces zero-mean white Gaussian noise with a variance matched to the target signal-to-noise ratio:

$$\mathbf{r(n) = x(n) + \eta(n)} \qquad \mathbf{(4)}$$

where η(n) represents independent and identically distributed complex Gaussian noise samples with variance σ^2 = N_0 / 2.

G. Receiver-Side Processing Chain

The receiver executes the inverse operations of the transmission chain. First, the cyclic prefix guard band is removed. The remaining time-domain block is processed using an N-point Fast Fourier Transform (FFT) to reconstruct the frequency-domain symbol vectors:

$$\mathbf{Y(k) = \sum_{n=0}^{N-1} r(n)\, e^{-j\, 2\pi\, k\, n\, /\, N}} \qquad \mathbf{(5)}$$

The received complex symbols are then demodulated using a minimum Euclidean distance criteria, mapping the coordinates back into the most likely binary bit sequences.

VII. SIMULATION RESULTS AND PERFORMANCE EVALUATION

The entire pipeline was simulated in MATLAB to evaluate system performance under varying signal conditions. The configuration parameters are detailed in Table I.

TABLE I: SYSTEM CONFIGURATION PARAMETERS

Subcarrier Count (N)	64
Cyclic Prefix Length (G)	16
Total Simulated Bits	10^6
Channel Profile	Additive White Gaussian Noise (AWGN)
Modulation Configurations	4-PSK (QPSK) and 8-PSK
SNR Iteration Range	0 dB to 20 dB (with 2 dB steps)

The simulated bit error rates for both 4-PSK and 8-PSK configurations across different SNR levels are presented in Table II and Table III.

TABLE II: SIMULATED ERROR RATES FOR 4-PSK OFDM

SNR (dB)	EMPIRICAL BIT ERROR RATE (BER)
0	0.07800

2	0.03700
4	0.01200
6	0.00240
8	0.00020
10	0.00001
12	0.00000
14	0.00000
16	0.00000
18	0.00000
20	0.00000

TABLE III: SIMULATED ERROR RATES FOR 8-PSK OFDM

SNR (dB)	EMPIRICAL BIT ERROR RATE (BER)
0	0.28500
2	0.19800
4	0.12700
6	0.08200
8	0.04100
10	0.01400
12	0.00400
14	0.00100
16	0.00020
18	0.00005
20	0.00000

The experimental comparison demonstrates an operational performance gap between the two systems. At an SNR baseline of 10 dB, the 4-PSK OFDM configuration achieves a BER of 0.00001, whereas the 8-PSK alternative exhibits a higher error rate of 0.01400. To achieve matching error bounds, the 8-PSK system requires approximately 4 dB of additional signal power. This behavior is directly related to the geometric reduction in phase spacing between adjacent symbols as the constellation density increases.

Fig. 4. Performance curves showing simulated Bit Error Rate (BER) trajectories versus increasing Signal-to-Noise Ratio (SNR) parameters for 4-PSK and 8-PSK configurations.

VIII. CONCLUSION

This research delivered a comprehensive evaluation and structural analysis comparing baseband OFDM systems implemented with 4-PSK and 8-PSK modulation layouts. The simulation results confirm that 4-PSK provides high noise margin immunity, making it optimal for channels with severe noise. Conversely, 8-PSK provides a 50% increase in spectral throughput, making it ideal for high-SNR environments where spectral efficiency is prioritized. This performance trade-off highlights the importance of incorporating dynamic, link-adaptive modulation strategies in next-generation high-speed wireless network designs.

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